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# EIGHTEENTH QUARTERLY PROGRESS REPORT

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## INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULANTS

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For

JET PROPULSION LABORATORY  
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## ENCAPSULATION TASK OF THE LOW-COST SILICON SOLAR ARRAY PROJECT

The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

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## I. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for the Low-Cost Silicon Solar Array project (LSA) funded by DOE. The goal of this program is to identify, evaluate, and recommend encapsulant materials and processes for the production of cost-effective, long-life solar cell modules.

During this last quarter a survey was made of elastomers for use as gaskets for the photovoltaic module. Of the wide variety of materials examined EPDM offered the optimum combination of low compression set and low cost. The preference for EPDM is borne out by its long history of use as an automobile gasket.

The commercial availability of materials that would be useful for sealants between the edge of the module and the gasket was investigated. Butyl sealants have the best combination of physical properties, low cost and a well-documented history of performance. A preferred composition has not yet been identified.

One laminating type pottant ethylene/methyl acrylate copolymer (EMA), and two casting polymers, polybutyl acrylate and polyurethane, have been under investigation this past quarter. An EMA formulation has been developed which is easily extrudable and cures to a high gel content.

So far only one commercial U.S. source(Quinn) of aliphatic polyurethane has been located. Work is continuing to improve reaction rate as well as to eliminate source(s) of bubble formation during module fabrication.

Considerable effort was spent in developing an improved polybutyl acrylate casting formulation providing high gel. Many viable curing systems are now available: however, the best formulation considering physical properties, freedom from bubbles as well as cure time utilizes Lupersol II (aliphatic peroxide) initiator. This initiator gives the desired gel after 20 minute cure at 45°C or 12 minute cure at 55°C.

## II. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of \$0.70 per peak watt ( $\$70/\text{m}^2$ ) (1980 dollars). The project is aimed at establishing the industrial capability to produce solar modules within the required cost goals by the year 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirements, and to maximize cost/performance.

Assuming a module efficiency of ten percent, which is equivalent to a power output of 100 watts per  $\text{m}^2$  in midday sunlight, the capital cost of the modules may be calculated at \$70.00 per  $\text{m}^2$ . Out of this cost goal only 20 percent is available for encapsulation due to the high cost of the cells, interconnects and other related components. The encapsulation cost allocation<sup>a</sup> may then be stated as \$14.00 per  $\text{m}^2$  which includes all coatings pollutants and mechanical supports for the solar cells.

Assuming the flat plate collector to be the most efficient design, photovoltaic modules are composed of seven basic construction elements. These elements are (a) outer covers; (b) structural and transparent substrate materials; (c) pollutants; (d) substrates; (e) back covers; (f) edge seals and gasket compounds, and (g) primers. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

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a. JPL Document 5101-68

Extensive surveys have been conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element.

The results of these surveys have also been useful in generating first-cut cost allocations for each construction element, which are estimated to be as follows (1980 dollars):

Construction Elements	Approximate Cost Allocation <sup>d.</sup> (\$/m <sup>2</sup> )
. Substrate/Superstrate (Load Bearing Component)	7.00
. Pottant	1.75
. Primer	0.50
. Outer cover	1.50
. Back cover	1.50
. Edge seal & gasket	1.85

From the previous work, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials. The following chart shows the materials of current interest and their anticipated functions:

(d) Allocation for combination of construction elements: \$14/m<sup>2</sup>.

Candidate Encapsulation Materials

<u>Load Bearing Component</u>	<u>Pottants</u>	<u>Cover Films</u>
<u>Superstrate Design</u>		<u>Back Covers</u>
. Soda-Lime Glass	. Ethylene/vinyl acetate	. Mylar
	. Ethylene/methyl acrylate	. Tedlar
<u>Substrate Design</u>	. Silicone 534-044(GE)	. Aluminum foil
. Fiberboard	. Poly-n-Butyl acrylate	. Stainless steel foils
. Flakeboard	. Aliphatic Polyurethanes	
. Mild steel		<u>Outer Covers</u>
. Glass reinforced concrete	(for use in both substrate and superstrate designs)	. Tedlar 100 BG 30 UT
		. 3M X-22417 Acrylic

Recent efforts have emphasized the identification and development of potting compounds. Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and inter-connect structure, and must serve as an optical coupling medium to provide maximum light transmission to the cell surface and optimize power output.

This report presents the results of the past quarter which has been directed at the continuing development and testing of pottants, outer covers, encapsulation processes and other components and techniques which may be useful for the fabrication of cost effective solar modules. The topics covered in this report are as follows:

(1) Solar module gaskets

Gaskets are needed for use as the supporting edge and carrier of the photovoltaic module. Manufacturers and other information sources are being surveyed for sources of gasket materials.

(2) Solar module sealants

Sealants are required to seal the edge of the photovoltaic module between the module edge and the rubbery gasket surrounding it. Chemical classes and commercially available products were surveyed for use in this application

(3) Pottants

Investigations of materials for use as solar module pottants were continued. Emphasis was placed on the determination of low temperature cure systems for the butyl acrylate syrup system and initial studies were begun on aliphatic polyurethane syrups. Work on ethylene/methyl acrylate, an alternate sheet lamination pottant to EVA, was also continued.

### III. SOLAR MODULE GASKETS

Gasket materials were surveyed for use as the supporting edge and carrier of the photovoltaic module when deployed in the field. The selection of appropriate materials for this application was initially based on the inherent and well known properties of elastomers. The first criteria of consideration being compression set, low temperature flexibility, weatherability and low cost. The properties of elastomeric materials were reviewed in general and resulted in first tier candidates:

<u>Elastomers rejected</u>	<u>Reason</u>
Natural rubber	Poor weatherability
Styrene/butadiene rubber	Poor weatherability
Butyl/halogenated butyl rubber	Poor weatherability
NBR	Poor weatherability
Polysulfide rubber	Staining
Fluoroelastomer	Very high cost
Hypalon	Low temperature flex and cost

<u>Elastomers selected for further evaluation</u>	<u>Reason</u>
Neoprene	Good weatherability
Ethylene/propylene rubber (EPDM)	Good weatherability/cost
Ethylene vinyl acetate	Good weatherability/cost
Silicone	Good weatherability

A useful document was also discovered through a literature search on materials suitable for solar module applications, entitled "Collector Sealants and Breathing". This was a study recently (February 1980) completed by Westinghouse Electric Corporation, Pittsburgh, PA, concerning the performance of elastomer gaskets and sealing compounds for use in solar thermal collector cells. In this study a wide variety of commercial compounds were evaluated in laboratory testing for properties such as ultimate elongation, compression set, hardness and the changes in these values after thermal and hygroscopic aging.



Compression set is seen as a critical property for the performance of elastomer gaskets. The weight of the module in the gasket when mounted at an angle applies a compressive load to the bottom of the gasket. If the rubber in this location creeps, compresses or otherwise changes its physical dimensions, the module will become loosely held in the frame and may become prone to damage. Compression set is a standard measurement of the elastomers resistance to deformation under load. The results of compression set and other tests were found in the Westinghouse report and appear in Table 8 in the appendix. A summary of the compression set values is as follows:

TABLE 1

SUMMARY OF COMPRESSION SET THERMAL AGING DATA

Material	Compound	Time (days) to Reach 50% Compression Set		
		125°C	150°C	175°C
Fluorocarbon	31-323-0731	7400*	150*	135
Silicone	NPC 80/40	100	21	5
Silicone	SE 7550	50	7	2
Silicone	HS 70	33	8	2
EPDM	Nordel 3300-11	103	50	27.5
Acrylic	Hycar 4054	105	28	10.5
Ethylene- acrylic	Vamac 3300-12A	35	8	4
Butyl	8EX-123	23	8	4.5

\* Extrapolation of an Arrhenius plot.

As may be seen in this summary, the fluorocarbon elastomer (Viton-DuPont) had the best compression set properties of the materials tested, followed by EPDM and then acrylic and silicone elastomers. Although not shown on the table, one of the difficulties experienced with the fluoro-elastomers is that of low temperature compression set, a characteristic that could present problems in geographic areas where severely cold winters are experienced. In terms of thermal aging the silicones are unquestionably

superior to all other elastomers, however their compression set values are low. The Westinghouse report contains recommendations for elastomers for this application that are believed to be viable candidates for both high and intermediate service applications, as follows:

1. High temperature
  - . Fluorocarbons
  - . Silicones
2. Intermediate temperature
  - . Acrylics
  - . Acrylic copolymers
  - . EPDM

The one physical property which is observed to limit service lives of elastomers most severely is elevated temperature compression set. Most promising approaches toward improving this characteristic involve moderate increase of cross-link density and increase of filler content.

The fluorocarbon rubber and the polyacrylic in particular suffer from excessive compression set at low temperatures. This difficulty is associated with high glass transition temperatures and thus with development of crystallinity during low temperature exposure. An approach to correction of this problem involves modification of the polymer chains in such a manner as to decrease regularity in the chain. This objective might be achieved by introduction of an additional monomer which can be copolymerized into the growing chain at random intervals. Other possibilities involve use of polymer blends or alloys and IPN (interpenetrating networks). An approach certain to be effective at reducing low temperature crystallinity involves incorporation of certain high molecular weight plasticizers, however this then presents problems with migration.

These properties and recommendations were then compared on a cost per pound basis. Typical gasket formulations were selected and costed out on a formulated cost per pound basis (see Table 9 , appendix) . The following table gives the comparison:

TABLE 2

SPRINGBORN LABORATORIES, INC.

COST vs COMPRESSION SET RECOVERY

Compounded Elastomer (Typical formulation)*	Comp. Set Range (%)	Set Recovery Range(%)	Compound Cost(\$1.1b)	Cost/Set Recovery Index
EPDM	10-30	90-70	0.58	0.64-0.83
Neoprene	15-25	85-75	0.87	1.02-1.16
EVA	20-35	80-65	0.85	1.06-1.31
Silicone	10-35	90-65	2.53	2.81-3.89

Compression set will vary tremendously depending on the characteristic of the individual compound. Different fillers and filler loadings will be responsible for this variation. Values listed are representative of typical formulations. The cost/set recovery index number was obtained by dividing (% set recovery/100) into cost per pound of compound. Lower values indicate better value regarding compression set-cost performance.

In conclusion, EPDM elastomers are thought to offer the overall best combinations of properties to give optimized cost/performance values. EPDM offers (1) the best compression set/cost ratio (2) low compound cost and the ability to tolerate high loadings of fillers (3) low gum stock cost (4) easy processability and extrusion, and (5) proven weatherability.

The automotive industry also appears to be in agreement with these conclusions;

. Automotive weatherstripping needs are satisfied by two different formulations. A dense formulation is used around the windows, windshield, and backlite, while a sponge formulation is used around doors. In addition, some extrusions utilize both a dense as well as a sponge formulation. This dual weatherstrip can either be extruded at the same time or extruded separately and fastened together with adhesives as a subsequent operation.

. EPDM is the dominant elastomer used for automotive weatherstripping. Several industry sources indicate that at least 90% of the domestic automotive weatherstripping is EPDM with the remaining 10% being manufactured with neoprene, norosex, and blends. There is some variation depending on whether dense weatherstripping or sponge weatherstripping is being considered.

. A typical weatherstripping formulation includes approximately 20-30% EPDM polymers. This percentage will produce a compound which has a tensile of approximately 1000-1500 psi. Usually, an automotive weatherstripping has a durometer value of 60-70.

In total, approximately 36 million lbs. of EPDM was used to manufacture domestic automotive weatherstripping in 1979.

The fact that EPDM has been used successfully by the automotive industry for long periods of time is an encouraging point. A history of performance of this materials in a related application is well documented and 20 year life has been demonstrated.

A survey was conducted into the sources of EPDM elastomers and companies with the capability to supply finished goods for this application. The manufacturers of EPDM were easy to identify, and are as follows:

<u>Manufacturer</u>	<u>Product Name</u>
Uniroyal	Royalene
Copolymer Rubber & Chemical Corp.	Epsyn
E.I.DuPont de Nemours	Nordel
Exxon	Vistalon
Goodrich	Epcar

These companies are only gum stock suppliers, however, and not compounders or fabricators. The number of commercial compounders numbers in the hundreds and the fabricators number in the thousands.

A survey was therefore undertaken to identify companies supplying gaskets specifically for the solar industries. Nine companies were found to be of assistance in this area.

All of the companies listed below have expressed an interest in our gasket problem when contacted. All have compounding and extrusion facilities for EPDM gasketing. Most have techniques for providing molded-in covers for gaskets. Companies are listed in order of probable success/experience based on telephone conversations.

## POTENTIAL GASKET SUPPLIES

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Pawling Rubber Co.	Pauling, N.Y.
Sperry Rubber & Plastics Co.	Brookville, IN
Johnson Rubber Co.	Middlefield, OH
Carlisle-Georgia	Middlefield, OH
Sheller-Globe Corp.	Portland, IN
General Tire & Rubber Co.	Akron, OH
Globe Rubber Works	Rockland, MA
Garlock, Inc.	Palmyra, N.Y.
Delford Industries, Inc.	Middletown, N.Y.

Contacts with the more important of these suppliers is summarized, as follows:

### Pawling Rubber Co.- Pauling, N.Y. (914) 855-100

. Charles Dubocq

Pawling has a line of gasket material, both compounds and finished cured gasket materials in both EPDM and silicone. Dubocq claims that they currently supply 90% of the solar collector industry with gaskets.

Compounds are extruded and the corners are injection molded into the stock to fit the panel dimensions. Gaskets are then cured and snapped into place on the panel like a rubber band. The gaskets must be sized for the job giving the process a specialized nature, but this eliminates the need for cutting, mitering and gluing which can be a messy job.

### Garlock, Inc., Palmyra, N.Y. (315) 597-4811

Garlock both formulates and processes gasket/weatherstripping material. They have several EPDM compounds (60 and 70A) which they feel might be appropriate. They have the facilities to provide extruded cured gaskets of the desired profile.

Delford Industries, Inc., Middletown, N.Y. (914)342-5805

Delford can supply an extruded rubber profile to meet any design specifications we can come up with. They do not do the "molded in corners" but they can cut and splice to supply a finished gasket.

Sperry Rubber and Plastics Co., Inc., Brookville, IN (317)647-4141

Sperry has had past experience in producing gaskets for the solar industry. They have their own laboratory, to compound formulation, compounding, and processing. They are quite versatile: can supply extruded cured channel gasket cut/mitred corners, can splice in vulcanized 90° corners, or can do injection molded corners (like Pawling).

Globe Rubber Co., Rockland, MA (617)871-3700

Globe can do compounding and profile extrusion to meet our specifications. They are somewhat unclear on complete gaskets (corners may be a problem for Globe) but are interested in seeing blueprints for a final design to determine what they can do.

Sheller Globe Corporation, Portland, IN (219)726-8171

They claim this type of gasketing is no problem. They do compounding, extrusion, and corners. He asks if the design of the panel can be modified to put a 3" radius on corners so that we could be saved the expense of the corner addition. Future contacts should go through Larry Wilcoxson in Portland, IN.

Johnson Rubber Co., Middlefield, OH, (216)632-1611

. George Krupa

Johnson is presently involved in solar gasketing for a variety of companies. They have complete compounding and extrusion facilities and are familiar with the corner production methods. They appear quite interested in solar application. Work with all materials except silicones.

General Tire and Rubber Co., Akron, OH (219)753-5131

\* John Simmermaker  
They claim that GT is involved in this area with most of the custom extrusion being done at their plant in Arkansas. Call: Al Hoffmann, Plant Mgr., (501)793-3179.

Carlisle-Geauga, Middlefield, OH (216)632-1671

Contact: Bob Connors. Geauga is familiar with solar gasketing and does considerable custom extrusion. They appear quite interested in development of a gasket material (Note: They have worked with collector panels and PV panels).

Uniroyal:(203)723-3000

This company makes a tubular extrusion designed to act as the collector pipe in solar thermal panels. The heat transfer fluid circulates directly through the tubing. This and other solar related rubber products are prepared by Uniroyal. All are based on their Royalene elastomer stock. Contact: Al Crepeau 203-723-3825.

All of these contacts are promising suppliers for custom molded gasketing for solar energy related applications and are aware of the performance/formulation relationships related to long term service in outdoor environments. A representative sample of manufacturers product literature (Pawling Rubber Co.) and comparison of product specifications and design application are given (Tables 10 and 11) in the appendix.

An additional piece of information is also felt to be useful with respect to this study. An ASTM specification for the selection of solar gasketing materials has been written. This specification, entitled "Rubber Seals Used in Flat Plate Solar Collectors, ANSI/ASTM D-3667-78), relates to test procedures, properties, classes and specifications for the appropriate selection of solar gasket and sealant material and is reproduced in its entirety (Table 12 ) in the appendix.

#### IV. SOLAR MODULE SEALANTS

Sealants are required to seal the edge of the photovoltaic module between the module edge and the rubbery gasket surrounding it. The sealant must function in performing the following functions: (1) adhesive to both surfaces (2) compliant and mechanically forgiving (3) glass transition temperature below  $-40^{\circ}\text{C}$  (4) serve as a barrier to liquid water (5) applicable to the modules construction by a commercial and high volume technique (6) have low water vapor transmission (7) weatherable (8) low cost. After considering these properties, two more were additionally added, solvent-free and non-curing. Non-curing sealants are thought to be a better choice due to their ability to be somewhat mobile along the gasket/edge interface and therefore impart a "self-healing" characteristic to the edge. Solvent-free is also desirable to prevent attack of the module edge and absorption by the pottant layer.

Major manufacturers of sealants were identified and contacted for products having the desired properties. The companies contacted are as follows:

Dow Corning , Midland , MI  
H.B. Fuller , St. Paul, MN  
General Electric , Waterford, N.Y.  
Gibson Homans , Twinsburg, OH  
Goss and Goss , San Francisco, CA  
Henkel Corp. , Minneapolis, MN  
Inmont Chemical , New York, N.Y.  
3M Company , St. Paul, MN  
Mortell , Kankakee, IL  
Polymeric Systems, Inc. , Pottstown, PA  
PRC , Glendale, CA  
Swift Adhesives , Chicago, IL  
Tremco , Cleveland, OH  
Pecona Chemical Corp. , Harleysville, PA



From these contacts a general survey of sealant compounds and manufacturers resulted and has been tabulated in Table 13.

This list of materials was then reduced further to refine the selection of suitable compounds. These sealants were first compared on the basis of generic chemical class and cost, as follows:

TABLE 3  
SEALANT USAGE COSTS

<u>Generic Class</u>	<u>Appx. Cost/Lb.<sup>a.</sup></u>	<u>Est. Cost/Module<sup>b.</sup></u>
Silicone	\$2.25 - 4.50	\$ 0.50
Polysulfide	2.25 - 5.70	0.27 - 0.68
Polyurethane	2.08 - 2.70	0.28
Polyamide	2.30 - 2.80	0.30
Acrylics	1.00 - 2.40	0.24
Butyls		
Hot melts	1.62	0.19
Tape compounds	3.67	0.44
Non-cure hot melt	2.00	0.24

a. High volume, non-specialty application

b. Costing basis: for a 1.2 m x 2.4 m module of appx. 280 W power output. Assume 1/8" (3 mm) round bead around edge; volume of sealant required, 58 cm<sup>3</sup>; assume specific gravity = 1.00: weight required appx. 58 gms, or 0.12 lbs.

Additionally, materials performance information has been tabulated according to the chemistry of available sealant compounds. as follows:

Table 4

Relative Performance - Various Sealant Base Materials

	Joint Movement Tolerance		
	Small (up to $\pm 5\%$ )	Moderate ( $\pm 5\%$ to $\pm 12\%$ )	Large ( $\pm 25\%$ )
Polymeric Base	Drying Oils Polybutenes Bitumens Neoprene	Butyl Acrylics Hypalon	Polysulphides Silicones Polyurethanes
Service Life	Up to 5 years	10 years min.	15 to 20 years
Cost	Low	Low to Moderate	High

Source: Adhesives Age: February, 1980, p. 34

It should be noted with respect to the two preceding tables that the compounds used for representative pricing are not necessarily usable for photovoltaic module application. The prices represent typical ranges and include sealants that are water based, have high solvent content and may cure with the evolution of an undesirable by-product (such as acetic acid in the silicones).

The automotive industry has encountered the need for edge sealing for many years now. in windshield applications to prevent the penetration of water between the glass and the gasket.

The auto industry was at one time largely solvent based systems; today they are rapidly moving to preformed tape, very low solvent systems (5% or less), and water based systems. Water based systems perform well once cured, but it takes much longer for the water to evaporate, hence tapes and low solvent systems are used when possible.

GM's experience typifies the industry since they began with two component polysulfide systems (which could be difficult to work with and had a very objectionable odor). Next came the butyl tape sealants which worked fine until windshields began being important for structural strength. The new wave is a one part polyurethane system that is applied in a continuous bead, although it is less cost effective than the butyls.

GM is very satisfied with the polyurethane even though it costs more, totaling about 50¢ to \$1.00 more per car. PU costs approximately 10¢/ft while butyl tape costs 5-6¢/ft. Two component polyurethane is excellent but difficult to handle and can be toxic. One component polyurethane is more costly and more water sensitive.

In addition to the requirements previously mentioned for the selection of sealants, a few other properties are also worth consideration.

Sag resistance is important. Despite the need for easy extrudability, non-sag grades must be stiff enough not to flow from vertical or overhead joints.

Hardness stability is also an important factor and refers to the corresponding increase in both the hardness and the cohesive modulus of the sealant. If this increase in hardness in actual use leads to a cohesive modulus greater than the adhesive strength, the bond will fail.

Bonding properties and durability are of prime consideration. The sealing properties of a sealant depend on its ability to adhere to the wall of the joint despite imposed stresses due to joint movement. This adhesion must remain strong despite exposure to harsh environments involving cyclical humidity and temperature swings.

labor and materials cost savings, and high quality performance. These tapes are almost always based upon butyl rubber or polyisobutylene due to their excellent adhesion, weathering and aging properties. Preformed tapes also have an unlimited shelf life, do not require special application or mixing equipment, application is quick, easy, clean, accurate and the seal forms immediately with no cure time or solvent evaporation.

Tapes can be formulated to achieve a wide variety of properties, the two broadest categories are low-resilients and resilient tapes. Resilience, softness, and adhesion properties are controlled by combining crosslinked butyl with regular butyl or bromobutyl compounds.

At this time, the butyl sealants appear to have the most desirable cost performance characteristics with well-documented history of use in long term field applications. Four major types of butyl sealants are available in the market. These are:

(1) Hot melt butyl sealants (curable)

These materials are applied at temperatures of about 400°F from a heated gun. They harden on cooling to a non-tacky material with excellent (60 psi) peel strength vs glass. Adhesion to plastics is considerably less. These sealants exhibit sag at temperatures above 150°F.

(2) Hot melt non-hardening butyl

These are similar to butyls from which butyl tapes are made. They are butyl rubber/isobutylene blends which have a higher butyl content than butyl caulking compounds. They have very low water vapor transmission. These compounds contain no solvent and are gunnable at raised temperature.

(3) Butyl tape (cold butyl)

These are butyl /isobutylene blends preformed into tape. Available in various forms, and varieties from many suppliers: Tremco, Pecora, Fuller and 3M. Non-hardening and useful in -40 to 400°F range.

(4) Butyl caulk

These are all solvent containing sealants, the solvent being necessary to impart gunnability to the sealants at room temperature. They tend to be hardening and non-tacky when cured. Probably need to be avoided due to solvent problems.

The type of butyl rubber used to seal windshields in the automotive industry is referred to as a "cold butyl" (or compression-setting or non-setting butyl). In use, this material is placed in the gasket in the form of a

long ribbon or tape. The glass is then pressed into the channel and the seal is formed from compression. Cold butyl has excellent adhesion to glass, has no cure time, requires no special equipment for use and is produced by the ton on a cost competitive basis. Commercial examples of this type of compound are Tremco 440 tape and 3M Company's product 5354.

Alternate to the preformed and compression fit type of application are the hot melt systems. Butyl based hot melt sealants are curable compounds that have been used extensively for the sealing of insulating windows and doors and have found to be superior to polysulfides and other sealants in the tests conducted by SIGMA (Sealed Insulated Glass Manufacturer's Association). The hot melt materials require special systems (hot melt guns) for application; however, the material handling is somewhat easier. In the solar module industry, the channel of the preformed gasket would probably be filled with sealant from a hot nozzle and then forced directly onto the edge of the module and permitted to set into place. Example of commercial hot melt butyl sealants are: National Adhesive product 72-6417, 3M Company's 3764 and H.B. Fuller's HM1081. The product manufactured by H.B. Fuller was tested and found to have superior adhesion and drying times<sup>a</sup>.

In addition to looking at commercial products available we also examined commercial applications for sealants. It is not possible, as a result of the survey to date, to definitively identify a single compound or class of compounds that optimize the cost/performance characteristics required. This survey is continuing the examination of the use of a wide range of commercial products and the history of successful applications. Additionally, laboratory evaluations will be conducted to assess product performance.

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a. MB Associates, San Ramon, California, Final report for JPL Contract No. 954882, Process Development for Automated Solar Cell and Module Production, June 30, 1980.

## V. POTTANTS

The pottant investigations at Springborn Laboratories are currently aimed at establishing two materials for the vacuum bag lamination process and two for the syrup casting process. The laminating materials of interest are EVA and the recently discovered EMA (ethylene/methyl acrylate) copolymer produced by Gulf Oil and Chemicals, Inc. The two casting syrups of interest are the poly-butyl acrylate system and the castable aliphatic liquid urethane system (available from H.J. Quinn, Malden, Mass ). Recent development work has emphasized the butyl acrylate system and attempts have been made to bring this system to full commercial readiness.

### Butyl Acrylate Syrup

The polybutyl acrylate pottant was originally investigated at JPL and found to be a desirable material for use as a pottant for reasons of its physical properties and also its photostability. A study of the photochemistry indicates that poly n-butyl acrylate (cured) forms a stable crosslinked network that undergoes chain scission and crosslinking at equal rates when exposed to ultraviolet radiation in the photoactive regions of the spectrum.<sup>a</sup> A study of the wavelength dependance of the photodegradation of the polyacrylates shows that photoreactivity continues up to 310 nm, only barely into the solar spectrum. This indicates that the acrylic elastomer will require less stabilization than materials with strong absorptions that may also reach far into the terrestrial ultraviolet.<sup>b</sup>

The compound originally prepared by JPL was composed of a premade butyl acrylate polymer that was then dissolved in a quantity of monomer to yield a pourable syrup. This syrup was then cured by heating in the presence of a free radical initiator. The cured material produced by this method is a water-white highly transparent elastomer of low modulus.

The difficulty experienced with early formulations was that of high cure temperature, long cure times and low gel contents.

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a. Gupta, A., Photodegradation of Polymeric Encapsulants of Solar Cell Modules, LSA document 5101-77, 8/10/78, Jet Propulsion Laboratory Pasadena, California.

b. Morimoto, K., and Suzuki, S., Journal of Applied Polymer Science, 16 , 2947, (1972).

Initial studies of the required cure conditions were also conducted at JPL using AIBN (azobis-isobutyronitrile) at a level of 0.01 weight percent as the free radical initiator and curing agent. Periods of four to sixteen hours at 80°C resulted in cured polymer with gel contents of 61% to 68% (by extraction) and over 90% conversion of the monomer to polymer. It was found that with this initiator, appreciable gel contents only occurred at temperatures in the range of 80°C - 90°C, and that temperatures above or below this range gave only small quantities of gel.

Subsequent work<sup>a</sup> concerned the modification of this base formulation with functional crosslinking agents to reduce the cure time/temperature and raise the gel contents. A successful formulation was discovered and a composition resulted that demonstrated a 68% gel content with complete cure of the syrup after one hour at 60°C. The new syrup formulation has the following composition:

A12805

Butyl acrylate monomer	60%
Butyl acrylate polymer	35%
1, 6-hexanediol diacrylate	5%

This material achieves cure after mixing with an appropriate initiator and then heating for the required period of time. The best results were achieved with the addition of 0.5% by weight of Lupersol 11<sup>b</sup>, which resulted in a 87% gel content after one hour at 50°C.

Further experiments were conducted on cure systems for the polybutyl acrylate pottant system with the hope of finding a room temperature cure chemistry that would remove the need for oven heating after module fabrication. The first experiments involved polymerization of the syrup at lower temperatures and the screening of lower temperature catalysts. The following results were obtained:

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- a. Willis, P. and Baum, B., Investigation of Test Methods, Material Properties and Processes for Solar Cell Encapsulants, Seventeenth Quarterly Report to Jet Propulsion Laboratories, Contract #954527, Springborn Laboratories, Enfield, Conn., September 1980.
- b. t-Butyl peroxy pivalate, from Lucidol Division, Pennwalt Corp., Buffalo, N.Y.

TABLE 5  
BUTYL ACRYLATE SYSTEM-  
LOW TEMPERATURE INITIATORS

Initiator	Level	Time to Cure(minutes)		
		Temp, 35°C	45°C	55°C
Lupersol 225	0.5 %	NP	NP	NP
Lupersol 11	0.5 %	NP	21	12
Benzoyl peroxide	0.5 %	NP	NP	47
Vazo 33W	0.5 %	5.5	4	Appx. 3
Lupersol 225	0.25 %	NP	32	20
Lupersol 11	0.25 %			
Lupersol 225	0.25 %	NP	NP	NP
Benzoyl peroxide	0.25 %			

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NP: No polymerization after one hour

The most efficient initiator resulting from this study was found to be Vazo 33W [2,2' -azobis(2,4-dimethyl-4-methoxyvaleronitrile) a DuPont product] which gave cure times of 5 1/2 minutes at 35°C and a gel content of 84%. Due to past difficulties experienced with some azo initiators<sup>a</sup>. (i.e. the evolution of nitrogen gas) experiments were continued with some peroxides in promoted systems to determine if the initiation temperature could be decreased. Promoters are additives used for this purpose and are widely used in room temperature curing of unsaturated polyester laminates. The effect of different promoters was determined with several peroxides of interest. The following table records the results of this investigation:

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a. These materials tend to evolve nitrogen when heated rapidly at high temperatures , however low temperature cures are usually bubble free.



TABLE 6

POLYMERIZATION TIMES WITH PROMOTED SYSTEMS<sup>(a)</sup>

Number	Initiator, 0.5%	Promoter, 0.1%	Time to Cure (minutes)			
			20°C	35°C	45°C	55°C
1	Benzoyl Peroxide	None	NP	NP	NP	47
2	"	Cobalt Napthenate	NP	NP	NP	27
3	"	Stannous Octoate	NP	70	34	12
4	"	Zinc Octoate	NP	NP	NP	19
5	Lupersol 11	None	NP	NP	21	12
6	Lupersol 11	Cobalt Napthenate	NP	NP	5	2
7	"	Stannous Octoate	NP	29	11.5	5.5
8	"	DBTDL <sup>(b)</sup>	NP	NP	18.5	7.5
9	"	Zinc Octoate	NP	NP	NP	10
10	Vazo 33W	None	39	5.5	4	3
11	"	Cobalt Napthenate	58	-	-	-
12	"	Stannous Octoate	30	4	3.5	2.5
13	"	DBTDL <sup>(b)</sup>	37	-	-	-
14	"	Zinc Octoate	38	-	-	-

(a) Under nitrogen to reduce air inhibition effects.

(b) Dibutyl Tin dilaurate

As may be seen from an examination of the table, a wide variety of pot lives, cure temperatures and cure times are available for use with this resin system. Probably the most useful cure systems are numbers 5, 7 and 10. These formulations present a wide range of conditions that may be selected for the onset of the desired cure.

As a general observation, the cure with the azo system appears to be slightly more efficient than the peroxide systems. Devolatilization of small samples of the cured formulations was performed in vacuum to measure the residual monomer by simple weight loss. The peroxide cured specimens showed a 2.7% loss after 24 hours under full vacuum (5-10 mm Hg) at a temperature of 60°C. The Vazo 33W cured systems had a weight loss of only 0.73%, indicating more efficient conversion.

A single experiment was done to examine the effects of modifying the formulation with a small amount of a comonomer in order to accelerate the cure rate. The standard butyl acrylate syrup formulation (A12805) was modified with the addition of 1% w/w of vinyl acetate monomer due to its fast forward rate constant with butyl acrylate. Initiating the system with Vazo 33W produced the fastest room temperature cure yet found, 19 minutes. Raising the level of vinyl acetate beyond the 1% did not give further effect. The previous experiments have shown that the azo system is activated to some degree with the use of a tin catalyst (experiment No. 12). The vinyl acetate modified system was further modified with 0.1% w/w of stannous octoate and resulted in a room temperature cure in 14 minutes (formulation A12837).

All the polymerizations, regardless of initiator, temperature, or time, demonstrated a very strong exotherm and fast rate of conversion. When the polymerization reaction starts a great deal of heat is produced and the conversion is essentially complete in minutes. Exotherms were measured with a thermocouple and thick sections of resin (0.75 inches) reached temperatures as high as 175°C in some cases. This exotherm is high enough to cause boiling of free monomer and the rapid generation of nitrogen from azo compounds. Additionally, the fast rate causes thermal stresses in the curing resin and, combined with polymerization shrinkage, results in fractures appearing in the thick sections. These effects do not appear to be troublesome in thin sections (100 mils) where the exotherm is dissipated. Plaques produced in standard molds cure with no difficulties to clear rubbery sheets with slight surface tack. The total integrated transmission was measured as 88.3%.

Mechanical test specimens were submitted for physical property determination and results recorded and compared to previous cure systems in the following table:

Table 7

Polybutyl Acrylate Pottant  
Cured Properties vs Initiator System

Initiator	Level (%)	Cure Time <sup>a.</sup> (min)	Cure <sup>b.</sup> Temperature °C	Tensile Strength (psi)	Ultimate Elongation (%)
Benzoyl Peroxide	0.5 %	60	60	138	50 %
Benzoyl Peroxide	0.1 %	180	60	181	100%
AIBN	0.5 %	60	60	267	100%
Lupersol 11	0.5 %	180	50	202	100%
Vazo 33W	0.5 %	60	25	138	74%
Vazo 33W	0.1 %	60	25	91	55%
Vazo 33W	0.5 %	60	25	99	63%
Stannous Octoate	0.1%				

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a. Minimum time permitted, cure may have taken place in much shorter time.

b. Temperature at which polymerization initiated, does not include exotherm.

As may be seen in the table, there is some dependance of physical properties on the type of initiator used. Generally, slightly elongations and noticably higher tensile strengths resulted from the use of the higher temperature cure systems. The use of Lupersol 11 is probably the best choice of initiator for the following reasons:

1. Good tensile strength
2. Good elongation
3. Non-aromatic (better weather stability)
4. Not a gas generator (like azo compounds)
5. Long pot life - will not cure at room temperature for 24 hours
6. Cure in 20 minutes at 45°C or 12 minutes at 55°C.

Springborn Laboratories will be ready to provide samples of the butyl acrylate pottant to industry within the next few months. Pilot plant facilities must be modified<sup>a</sup> for preparation of the syrup on a larger scale before evaluation quantities become available.

#### Aliphatic Polyurethane

Aliphatic urethanes were surveyed in order to make a go - no go decision as to the continuation of work on this type of pottant system. A number of photovoltaic module manufacturers were contacted and they expressed interest in this class of casting materials. One of the difficulties experienced in the laboratory use of the pourable urethane systems has been that of moisture reactivity and consequent bubbling of the pottant. Experimental modules prepared at Springborn all showed difficulty in this respect and no modules could be prepared without small bubbles appearing. Modules prepared with hardboard substrates were conspicuously the worst due to the hygroscopic nature of the wood fibers. A number of module manufacturers have also conducted in-house experiments with pourable urethane systems. They report no difficulties moisture sensitivity and bubbling and are still drawn to this class of pottants, especially for the superstrate design. This discrepancy is being investigated at Springborn Laboratories. It is felt that the urethane is suitable for this

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a. Requires use of wiped film evaporator.

design and that the protective covering of glass may result in acceptable lifetimes in outdoor exposure.

The aliphatic urethanes were surveyed due to the general interest in this area and manufacturers were contacted to answer, the following questions:

- (1) What grades are available that are aliphatic, pourable, and solvent free?
- (2) What catalyst systems are available and what is the range of cure conditions?
- (3) What is known about the stabilization of urethanes and what additives are recommended for thermal/oxidative and UV protection?

Specific companies contacted included Mobay Chemical Co., H.J. Quinn Co., Henkel Corporation, Morton Chemical Company and Upjohn Chemical Company. Information on stabilizers was also obtained from Borg Warner, American Cyanamide, and Ciba Geigy.

Still, the only commercially available aliphatic urethane casting syrup is the Quinn 621/626 system. The Henkel material (MX-152) received a few months ago is not a commercial product. Upjohn and Morton Chemical Companies offer no aliphatic systems that would be usable in this application. Mobay has no off-the-shelf products that could be used, however they showed interest in having a meeting at Springborn in the future to discuss the requirements more fully and possibly offer a specialized product for this purpose. They suggest that products could result based on their Desmodur L-2291A (fully hydrogenated methylene diphenyl diisocyanate) or from adducts employing hexamethylene diisocyanate (HMDI). Mobay will be contacted in the future for a meeting.

Catalysis of these systems is more of a problem than with the aromatic resins. Aliphatic urethanes are known for being sluggish in terms of their polymerization times. The most widely recommended catalysts are the tin compounds, especially dibutyl tin dilaurate. This catalyst is specifically recommended for the Quinn system and may be varied in amount to change the gel times (typically 30 min). Manufacturers agree that this compound is much more successful than stannous octoate or zinc octoate. Amine catalysts should be avoided due to color formation upon aging and weathering.

Some good input was obtained concerning stabilization of aliphatic urethanes. Mobay and Ciba-Geigy both recommended the same system as follows; 0.5 phr Tinuvin 770, 0.5 phr Tinuvin 328, 0.1 phr Irganox 1010. This is felt by both companies to be a synergistic combination that has a minimal effect on the cure of the resin. American Cyanamide offered a different formulation; 0.5 phr Cyasorb UV-5411 (a benzotriazole) with about 0.1 phr of Cyanox 1735, a phenolic/phosphite combination as the antioxidant. Samples of all these materials are being supplied and will be evaluated upon arrival.

### Ethylene / methyl acrylate

The fully compounded version of ethylene-methyl acrylate copolymer (formulation All877) was run through the Brabender laboratory extruder to determine the processing conditions required to produce an extruded sheet suitable for the lamination approach to module fabrication. As with the EVA counterpart, the resin pellets (type 2205) were tumble blended with the peroxide and stabilizing additives and run directly into the hopper of the extruder. The resulting sheet materials was of good quality, more easily controllable than EVA and may be extruded in thinner gauges. Extrusion proceeded smoothly at a barrel temperature of 100°C and a die temperature of approximately 80°C. The throughput was steady and approximately the same speed as the EVA, with a barrel residence time of approximately 3-4 minutes.

Sheet resulting from this extrusion procedure was cured and analyzed for gel content. A low gel content of only 40% resulted. This is felt to be due to the higher melt viscosity of the EMA resin and insufficient blending of the peroxide during the extrusion process. This problem is expected to disappear with the use of the large (2 1/2") extruder and preparations are in progress for a trial run of 50 to 150 pounds of resin. The higher melt index resin (TD 938) was ordered from Gulf Oil Chemicals Inc. in sufficient quantity to reevaluate the formulation on a laboratory scale and also for the large trial run. This new material (melt index 6 as opposed to 2) was compounded in the same manner as the previous copolymer and extruded without difficulty. Gel contents obtained with this formulation were found to be in the range of 74-78%. The blending properties of this resin are felt to be superior and future formulations will be based on it.

Springborn Laboratories anticipates that industrial evaluation quantities of compounded and extruded pottant grade EMA will become available within the next three months period of time.

## VI.. CONCLUSIONS

1. Survey was made of elastomers that could have potential as gasket materials for use as the supporting edge and carrier of the photo-voltaic module. The most critical properties are the need for low compression set and low cost. Of the four elastomers of interest- EPDM, Neoprene, EVA and silicone - EPDM elastomers are the most cost effective. EPDM is the principal elastomer used for automotive weather-stripping. A survey was first conducted into the sources of EPDM elastomers and companies with the capability of supplying finished goods. Nine companies were identified who supply gaskets specifically for the solar industry.

2. A study was also made of the commercial availability of sealants. Sealants are required to seal the edge of the photovoltaic module between the module edge and the rubber gasket surrounding it. Non-curing sealants are believed to be a better choice due to their ability to impart a self-healing characteristic. Major manufacturers were identified and contacted for products having the desired properties. Two general types of sealants offer the highest potential-tapes and low solvent systems. Butyl sealants appear to have the most desirable cost/performance characteristics. Four major types of sealants are available in the market - hot melts, hardening and non-hardening, tapes and caulks. Since it is not yet possible to identify a final compound that optimizes cost/performance, this survey is continuing.

3. Development of both laminating and casting type potting compounds is continuing. EMA (ethylene/methyl acrylate copolymer) compound ( Gulf Chemicals) containing peroxide and stabilizers and based on a two melt index resin was easily extruded but on curing gave only a 40% gel content. Use of a six melt index EMA, however, yielded a 76% gel. Future formulations will be based on this material.



4. Two casting pottants were investigated - aliphatic polyurethane and butyl acrylate. Aliphatic polyurethanes were surveyed due to general interest as well as the need of having a back-up material for butyl acrylate casting syrup. A number of companies were contacted but the only commercial urethane presently available is from Quinn. A urethane from Henkel is still experimental. Catalysis of an aliphatic urethane is more of a problem than with the aromatic because of sluggish reaction rates. However, the aliphatic is more UV stable and efforts will continue to develop a useful system.

5. Improved formulations for polybutyl acrylate, a liquid pottant used in the casting encapsulation process have been developed. A new formulation providing 68% gel after one hour cure at 60°C was:

Butyl acrylate monomer	60%
Butyl acrylate polymer	35%
1, 6 - Hexanediol acrylate	5%

Further experiments were conducted to find a room or lower temperature curing system. A wide variety of pot lives , cure temperatures and cure times are available with this resin system including room temperature cures with Vazo 33W combined with promoters. The best initiator taking into consideration physical properties of the cured polybutyl acrylate is probably Lupersol-11. Lupersol-11 formulations have good tensile strength and elongation, no gas generation unlike azo compounds, long pot life and 20 minute cure at 45°C or 12 minute cure at 55°C.

## A P P E N D I X

Table 8

ELASTOMERS FOR SOLAR MODULES

CLASS PS ELASTOMER SCREENING TEST<sup>1</sup>

<u>Class PS Material</u>	<u>Hardness<sup>1</sup> Grade</u>	<u>Ultimate Elongation</u>	<u>Compr. Sec 70 h, 150°C<sup>2</sup></u>	<u>Compr. Sec 166 h, 10°C</u>	<u>Hardness Change<sup>2</sup></u>	<u>Ultimate Elongation Change<sup>2</sup></u>	<u>Tensile Strength Change<sup>2</sup></u>	<u>Volatiles Lost<sup>2</sup></u>
<u>Silicone</u>								
SE-7550	5	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>
Silastic 747	7	P	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P	P	P
HS-70	7	P <sup>+</sup>	P	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>
<u>EPDM</u>								
E-633	7	P <sup>+</sup>	F <sup>-</sup>	F <sup>-</sup>	P	F <sup>-</sup>	F	F <sup>-</sup>
78E-09-28-2	6	P <sup>+</sup>	F <sup>-</sup>	F <sup>-</sup>	F <sup>-</sup>	F <sup>-</sup>	P <sup>+</sup>	P
Nordel 3300-11	8	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P
<u>Fluorocarbon</u>								
Viton 31323-0731	8	P <sup>+</sup>	P <sup>+</sup>	F <sup>-</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>
Viton PLV 1008	8	P <sup>+</sup>	P <sup>+</sup>	F <sup>-</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>
<u>Epichlorohydrin</u>								
HM 14-10-1	6	P <sup>+</sup>	F <sup>-</sup>	P <sup>+</sup>	P	P	P	F <sup>-</sup>
HM 13-SEC3-2	7	P <sup>+</sup>	F	P <sup>+</sup>	P	P	P <sup>+</sup>	P
HM 13-27-1	8	P <sup>+</sup>	F	P <sup>+</sup>	F	F	P	F <sup>-</sup>
<u>Ethylene Acrylic</u>								
Vamac 3300-12	7	P <sup>+</sup>	F	F <sup>-</sup>	P <sup>+</sup>	F	P <sup>+</sup>	F <sup>-</sup>
<u>Chlorosulfonated Polyethylene</u>								
Hypalon 3300-10	7-8	P <sup>+</sup>	F <sup>-</sup>	F <sup>-</sup>	P <sup>+</sup>	P	P <sup>+</sup>	P <sup>+</sup>
<u>Polyacrylic</u>								
210-108-35-1	6-7	F	P <sup>+</sup>	P	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>
<u>Bromobutyl</u>								
8EX-122	6	P	F	F	P <sup>+</sup>	F	P	F <sup>-</sup>
<u>Butyl</u>								
8EX-123	5-6	P <sup>+</sup>	P <sup>+</sup>	F <sup>-</sup>	P <sup>+</sup>	P <sup>+</sup>	P <sup>+</sup>	F <sup>-</sup>
SR 35020	5	P <sup>+</sup>	F <sup>-</sup>	P <sup>+</sup>	P <sup>+</sup>	P	F <sup>-</sup>	F <sup>-</sup>

<sup>1</sup>(Hardness grade x 10) ± 5 = Shore A durometer hardness

<sup>2</sup>Materials exposed to 150°C/70 h

P = pass by relatively small margin

P<sup>+</sup> = pass by substantial margin

F = fail by relatively small margin

F<sup>-</sup> = fail by substantial margin

Source : M. A. Mendelsohn, et al., Collector Sealants and Breathing , Report number ALO-15362-1 , by Westinghouse Electric Corporation, Pittsburgh, Pa., Feb. 20, 1980 . Work performed under contract no. DE-ACO4 -78CS15362

TABLE 9

TYPICAL ELASTOMER FORMULATIONS AND COST

Raw Material Costs

Resin Gum Stocks:	\$ /lb
Neoprene WRT	1.23
Vynathane EY-904-25	1.04
Epsyn 5508	0.8625
Epsyn N557	0.7080
Silastic GP437	2.37
Fillers:	
Carbon Black (typical)	0.50
Clay (typical)	0.50
Cabosil MS-7	2.77
Process oil	0.50

Formulations (representative)

1. Neoprene -weather resistant Cost: \$0.87/lb.

Neoprene WRT	100
Carbon Black	55
Clay	20
2. EPDM-Weatherstripping compound (\$0.58/lb)

Epsyn 5508	70
Epsyn N557	45
Carbon Black	200
Process Oil	130
3. EVA (\$0.85/lb)

Vynathene EY904-25	100
Carbon Black	55
4. Silicone (\$2.53/lb)

Silastic GP-437	100
Cabosil MS-7	65

Table 10

## Solar Module Gaskets - Product Specification

### Typical Manufacturer's Literature

#### ELASTOMER (POLYMER) SELECTION

Experience has shown that most solar collector sealing applications are best handled with an elastomer of either an EPDM or silicone base.

##### PAWLING E633 EPDM

Pawling Rubber has developed a high strength EPDM elastomeric material specifically compounded to meet the physical requirements of collector sealing (glazing) where the temperature at the seal will be 250°F or less. A majority of the collectors in use today can be adequately glazed with our E633 EPDM, for although the highest anticipated stagnate temperature at the collector plate surface may exceed 300°F, the temperature at the seal will be lower. Collectors sealed (glazed) with gaskets made by Pawling from our E633 EPDM have passed the HUD thirty day stagnation tests.

##### PAWLING 96-B-24 SILICONE / PAWLING 80623 SILICONE

Pawling Rubber has developed this special silicone elastomeric material for use in solar applications where the temperature at the component will continually exceed 300°F. This may be the case with spacers or thermal breaks in contact with or in very close proximity to the collector plate, or on some inner seals in double glazed units. Collectors sealed (glazed) with gaskets made by Pawling from our 96-B-24 and 80623 Silicone have passed the HUD thirty day stagnation tests.

The physical characteristics and specifications applying to Pawling E633 EPDM and Pawling 96-B-24 and 80623 Silicone are listed below so that you may have more exacting descriptions of the materials to compare the strengths and limitations of each.

#### COMPARATIVE DATA

Resistance To:	Pawling E633 EPDM Ethylene Propylene Polymer	Pawling 80623 Silicone Pawling 96-B-24 Silicone Polysiloxane Polymer	* These temperature ranges are recommended limits for normal service life. Occasional or intermittent temperature exposure above these limits may cause slight accelerated heat aging which results in some hardening and loss of flexibility of that portion of the part exposed to the high temperature. However, the seal will not cease functioning.
Water Absorption	Excellent	Excellent	
Oxidation	Excellent	Excellent	
Ozone	Outstanding	Outstanding	
Sunlight Aging (Ultra Violet)	Outstanding	Excellent	
Heat Aging	Excellent	Outstanding	
Low Temperature	Excellent	Outstanding	
Temperature Range	-60°F to +300°F*	-60°F to +500°F*	
Rebound Hot	Excellent	Excellent	
Cold	Excellent	Excellent	

Volatilization (outgassing) - Used as recommended, outgassing of E633 EPDM, 96-B-24 and 80623 silicone is infinitesimal. No measurable light transmission degradation has been noted in the field or laboratory.

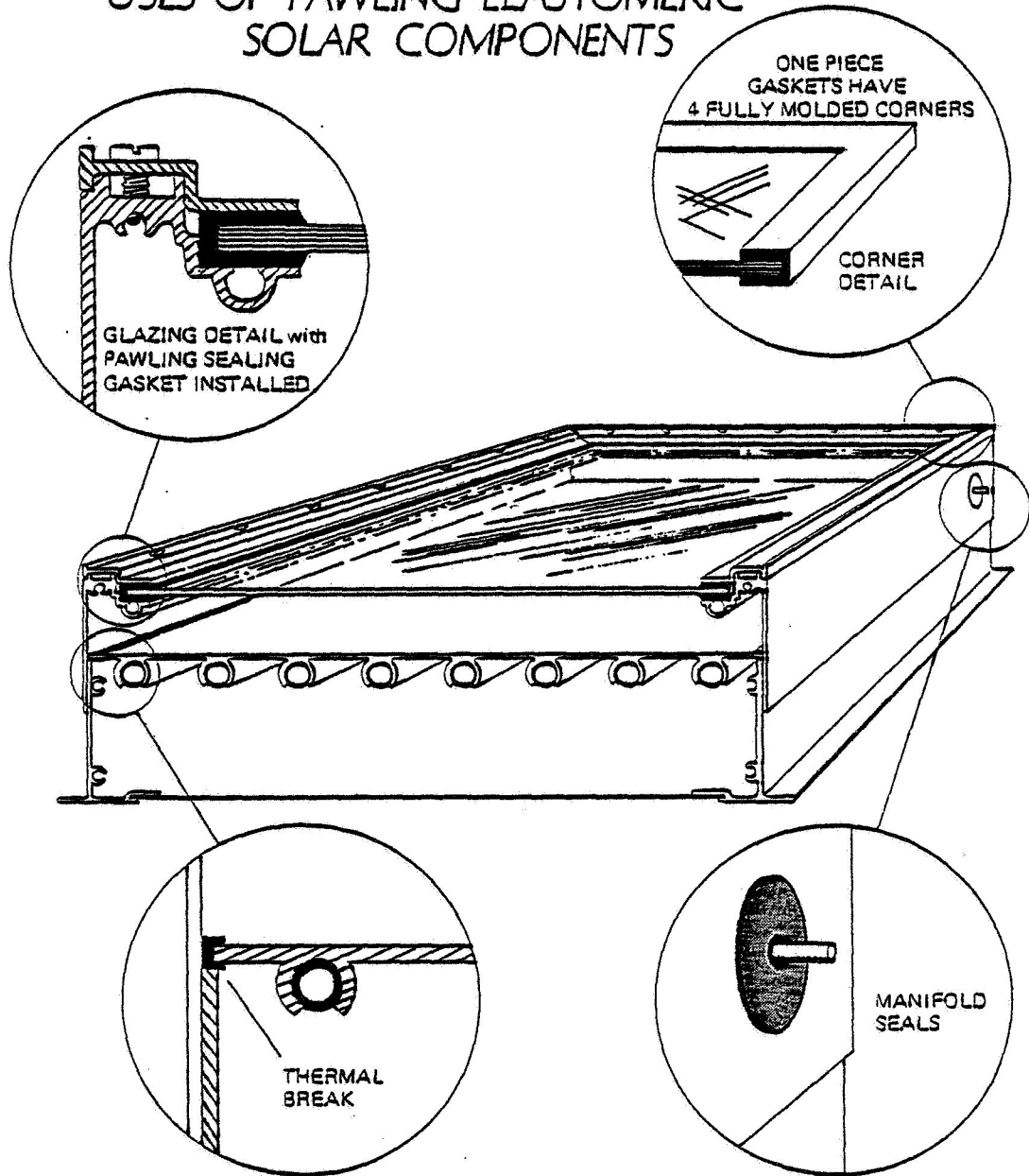
96-B-24 and 80623 SILICONE			E633 EPDM		
Specification ASTM D2000 5GE608			Specification ASTM D2000 3BA 620 A <sub>14</sub> B <sub>13</sub> C <sub>12</sub> F <sub>17</sub> Z <sub>1</sub> Z <sub>2</sub> Z <sub>3</sub> Z <sub>4</sub> Z <sub>5</sub>		
A <sub>19</sub> B <sub>37</sub> C <sub>12</sub> E <sub>14</sub> F <sub>10</sub> G <sub>3</sub> H <sub>11</sub> I <sub>2</sub> J <sub>1</sub> K <sub>2</sub> L <sub>3</sub> M <sub>4</sub> N <sub>5</sub>			Original Properties:		
Original Properties:	As Specified	As Obtained	Durometer (Shore A)	As Specified	As Obtained
Durometer (Shore A)	60 ± 5	60	Tensile Strength	60 ± 5	60
Tensile Strength	Min. 700 psi	900 psi	Elongation	Min. 2000 psi	2200 psi
Elongation	Min. 200%	225%	Tear Resistance (G <sub>21</sub> )	Min. 400%	425%
Oven Aged 70 Hrs @ 437°F (A <sub>19</sub> )			Compression Set 22 Hrs @ 158°F (B <sub>13</sub> )		200
Durometer Change	Max. +10	+4	Oven Aged 70 Hrs @ 212°F (A <sub>14</sub> )		
Tensile Change	Max. -25%	+3%	Durometer Change	Max. +10	+5
Elongation Change	Max. -30%	-7%	Tensile Change	Max. -25%	-4%
Compression Set 22 Hrs @ 347°F (B <sub>37</sub> )			Elongation Change	Max. -25%	-10%
% Deflection	Max. 25%	20%	Compression Set 22 Hrs @ 158°F (B <sub>13</sub> )		
Water Immersion 70 Hrs @ 212°F (E <sub>14</sub> )			% Deflection	Max. 25%	20%
Volume Change	± 5%	+0.5%	Water Immersion 70 Hrs @ 212°F (E <sub>14</sub> )		
Ozone Resistance 168 Hrs @ 50 PPHM +104°F @ 20% Strain (C <sub>12</sub> )			Volume Change	+10%	+0.5%
No Cracking or Checking - Passed			Ozone Resistance 168 Hrs @ 50 PPHM +104°F @ 20% Strain (C <sub>12</sub> )		
Cold Test, Flexibility Brittle Point @ -85°F (F <sub>110</sub> )			No Cracking or Checking - Passed		
No cracking before or after impact - Passed			Cold Test, Flexibility Brittle Point @ -40°F (F <sub>17</sub> )		
Staining Test: Non-staining as per ASTM D 925, method B - Non-staining (P)			No cracking before or after impact - Passed		
Special Tests: Samples baked 14 days @ 350°F in a tightly covered 500 ml Berzelius Beaker on a hot plate			Special Tests: Samples baked 7 days @ 250°F in a tightly covered 500 ml Berzelius Beaker on a hot plate (Z <sub>1</sub> - Z <sub>4</sub> )		
Z <sub>1</sub> - Maximum weight loss 0.04%			Z <sub>1</sub> - No oily emissions, fogging or crystalline formations within the beaker or on the glass cover plate.		
Z <sub>2</sub> - No appreciable fogging of glass cover plate or beaker sides.			Z <sub>2</sub> - Maximum weight loss 1.0%		
Z <sub>3</sub> - Maximum +5 durometer change (Shore A)			Z <sub>3</sub> - Maximum +5 durometer change (Shore A)		
Z <sub>4</sub> - No cracking when flexed 180° several times.			Z <sub>4</sub> - No cracking when flexed 180° several times		
			Special Test: Tear resistance. (Z <sub>5</sub> )		
			Z <sub>5</sub> - Tear resistance (ASTM D 624, Die C) minimum 200 p.s.i.		

Inasmuch as Pawling Rubber Corporation has no control over the use to which others may put the material, it does not guarantee that the same results as those described herein will be obtained. Each user of the material should make his own tests to determine the material's suitability for his own particular application.

Table 11

Typical Manufacturer's Literature  
Solar Module Gaskets - Design Application

A TYPICAL COLLECTOR ASSEMBLY SHOWING  
USES OF PAWLING ELASTOMERIC  
SOLAR COMPONENTS



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AMERICAN NATIONAL  
STANDARD

ANSI/ASTM D 3667 - 78



D 3667

7.2.2 Extruded Seals:  
7.2.2.1 Commercial Dimensions - RMA A2-F3.

## Standard Specification for RUBBER SEALS USED IN FLAT-PLATE SOLAR COLLECTORS<sup>1</sup>

This Standard is issued under the fixed designation D 3667; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last approval.

### 1. Scope

1.1 This specification covers the general requirements for materials used in rubber seals of flat-plate solar collectors, except vertically mounted passive collectors. Particular applications may necessitate other requirements that would take precedence over these requirements when specified.

1.2 The design requirement pertains only to permissible deflections of the rubber during thermal expansion or contraction of the seal in use and the tolerances in dimensions of molded and extruded seals.

1.3 This specification does not include requirements pertaining to the fabrication or installation of the seals.

### 2. Applicable Documents

- 2.1 *ASTM Standards*:  
C 661 Test for Indentation Hardness of Elastomeric-Type Sealants by Means of a Durometer<sup>2</sup>  
C 717 Definitions of Terms Relating to Building Seals<sup>3</sup>  
C 719 Test for Adhesion and Cohesion of Elastomeric Joint Sealants Under Cyclic Movement<sup>4</sup>  
D 395 Tests for Rubber Property - Compression Set<sup>5</sup>  
D 412 Tests for Rubber Properties in Tension<sup>6</sup>  
D 865 Test for Rubber Deterioration by Heating in a Test Tube<sup>7</sup>  
D 1149 Test for Rubber Deterioration - Surface Oxidation Cracking in a Chamber (Flat Specimens)<sup>8</sup>  
D 1229 Test for Rubber Property - Compression Set at Low Temperature<sup>9</sup>  
D 1339 Recommended Practice for Rub-

ber - Standard Temperatures and Atmospheres for Testing and Conditioning<sup>10</sup>  
D 1415 Test for Rubber Property - International Hardness<sup>11</sup>  
D 1566 Definitions of Terms Relating to Rubber<sup>12</sup>  
D 2137 Test for Rubber Property - Brittleness Point of Flexible Polymers and Coated Fabrics<sup>13</sup>  
D 2240 Test for Rubber Property - Durometer Hardness<sup>14</sup>  
D 3182 Recommended Practice for Rubber - Materials, Equipment, and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets<sup>15</sup>  
D 3183 Recommended Practice for Rubber - Preparation of Pieces for Test from Other Than Standard Vulcanized Sheets<sup>16</sup>

2.2 *Other Standards*:  
RMA Handbook - Rubber Products: Molded, Extruded, Lathe Cut, and Cellular<sup>17</sup>

### 3. Classification

3.1 *Types*:

3.1.1 *Type C*, intended for use in cold climates (below -10°C in winter).

3.1.2 *Type W*, intended for use in warm climates (above -10°C in winter).

3.1.3 *Type H*, intended for use in hot climates (above 10°C in winter).

3.1.4 *Type S*, intended for use in semi-arid climates (above 10°C in winter).

3.1.5 *Type T*, intended for use in tropical climates (above 20°C in winter).

3.1.6 *Type U*, intended for use in sub-tropical climates (above 20°C in winter).

3.1.7 *Type V*, intended for use in arid climates (above 20°C in winter).

3.1.8 *Type X*, intended for use in semi-arid climates (above 20°C in winter).

3.1.9 *Type Y*, intended for use in arid climates (above 20°C in winter).

3.1.10 *Type Z*, intended for use in semi-arid climates (above 20°C in winter).

3.1.11 *Type AA*, intended for use in arid climates (above 20°C in winter).

3.1.12 *Type AB*, intended for use in semi-arid climates (above 20°C in winter).

3.1.13 *Type AC*, intended for use in arid climates (above 20°C in winter).

3.1.14 *Type AD*, intended for use in semi-arid climates (above 20°C in winter).

3.1.15 *Type AE*, intended for use in arid climates (above 20°C in winter).

3.1.16 *Type AF*, intended for use in semi-arid climates (above 20°C in winter).

3.1.17 *Type AG*, intended for use in arid climates (above 20°C in winter).

3.1.18 *Type AH*, intended for use in semi-arid climates (above 20°C in winter).

3.1.19 *Type AI*, intended for use in arid climates (above 20°C in winter).

3.1.20 *Type AJ*, intended for use in semi-arid climates (above 20°C in winter).

3.1.21 *Type AK*, intended for use in arid climates (above 20°C in winter).

3.1.22 *Type AL*, intended for use in semi-arid climates (above 20°C in winter).

3.1.23 *Type AM*, intended for use in arid climates (above 20°C in winter).

3.1.24 *Type AN*, intended for use in semi-arid climates (above 20°C in winter).

3.1.25 *Type AO*, intended for use in arid climates (above 20°C in winter).

3.1.26 *Type AP*, intended for use in semi-arid climates (above 20°C in winter).

3.1.27 *Type AQ*, intended for use in arid climates (above 20°C in winter).

3.1.28 *Type AR*, intended for use in semi-arid climates (above 20°C in winter).

3.1.29 *Type AS*, intended for use in arid climates (above 20°C in winter).

3.1.30 *Type AT*, intended for use in semi-arid climates (above 20°C in winter).

climates (above -10°C in winter).

3.2 *Grades*:

3.2.1 Grade designations represent differing degrees of hardness as follows:

3.2.1.1 *Grade 2*, hardness of 20 ± 5.

3.2.1.2 *Grade 3*, hardness of 30 ± 5.

3.2.1.3 *Grade 4*, hardness of 40 ± 5.

3.2.1.4 *Grade 5*, hardness of 50 ± 5.

3.2.1.5 *Grade 6*, hardness of 60 ± 5.

3.2.1.6 *Grade 7*, hardness of 70 ± 5.

3.2.1.7 *Grade 8*, hardness of 80 ± 5.

Note 1 - The grade to be used in a particular application depends on the design of the seal and must be specified by the designer.

### 3.3 *Classes*:

3.3.1.1 Class PS seals shall be classified as follows:

3.3.1.1.1 Class PS, preformed rubber seal.

3.3.1.1.2 Class SC, sealing compound.

Note 2 - Class SC material should not be used in designs where the seal is under mechanical stress.

### 4. Definitions

4.1 Refer to the definitions of terms in Definitions C 717 and D 1566.

### 5. Materials

5.1 Seals shall be made from rubber compounds that are impermeable to ultraviolet light and when vulcanized, conform to the requirements in Section 6.

### 6. Requirements

6.1 Class PS material shall conform to the requirements given in Table 1.

6.2 Class SC material shall conform to the requirements given in Table 2.

### 7. Dimensions

7.1 The design of the seal shall not permit the rubber to deflect more than 25% in any direction during thermal expansion and contraction of the solar collector.

Note 3 - If the thermal coefficient of linear expansion for the rubber is not known, a value of 0.0003/K may be assumed for design purposes.

7.2 The tolerances in dimensions shall conform to the following designations in the RMA Handbook:

7.2.1.1 *Molded Seals*: Dimensions - RMA A2-F3-T.032.

7.2.1.2 *Critical Dimensions* - RMA A2-F3-T.032.

7.2.1.3 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.4 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.5 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.6 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.7 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.8 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.9 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.10 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.11 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.12 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.13 *Other Dimensions* - RMA A2-F3-T.032.

7.2.1.14 *Other Dimensions* - RMA A2-F3-T.032.

7.2.2 Extruded Seals:  
7.2.2.1 Commercial Dimensions - RMA A2-F3.

### 8. Workmanship

8.1 Class PS seals shall be free of blisters, checks, cracks, and other imperfections that can affect their ability to make or maintain a water-tight seal.

8.2 Class SC material shall be uniform in composition and be free of defects that may affect serviceability.

### 9. Test Methods

9.1 *Class PS Material* - Prepare the specimens as prescribed in Recommended Practice D 3183 and test the material in accordance with the test methods given in Table 1. For control of production, specimens may be taken from standard test sheets prepared in accordance with Recommended Practice D 3182, using the same unvulcanized material used to prepare the seals and vulcanizing the material at the same temperature used for the seals to an equivalent state of vulcanization.

9.2 *Class SC Material* - Prepare five sheets approximately 150 by 150 by 2 mm in accordance with instructions supplied with the sealing material. Also, prepare five adhesion specimens in accordance with Method C 719. Preferably, prepare each sheet and adhesion specimen from material in a different container. Condition the sheets and adhesion specimens for 14 days at a temperature of 23°C and relative humidity of 50%. Test the material in accordance with the test methods given in Table 2.

9.3 Determine volatiles lost from the difference in mass of the specimens before and after heating for 166 h at the temperature given in Table 1 or 2 and as prescribed in Method D 865.

9.4 Determine volatiles condensable at 23°C from the difference in mass of the outlet tubes before and after heating the specimens for 166 h at the temperature given in Table 1 or 2 in accordance with Method D 865. If necessary, cool the exposed portion of the outlet tube with a stream of air to maintain a temperature of 23 ± 2°C. If any volatiles condense on the inlet tube or other parts of

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the apparatus, add the mass of this condensed material to the mass of the material on the outlet tube.

## 10. Inspection and Rejection

10.1 *Class PS Material*—Manufacturers of preformed seals may use their quality control systems for production inspection to assure the seals conform with this specification, provided appropriate records are kept. In case of dispute regarding the quality of a delivered product, a sample of five seals shall be taken from the lot and tested for compliance with this specification. If one of the five seals does not conform, a second sample of five seals may be taken and tested. If two or more of the ten seals do not conform, the lot may be rejected.

10.2 *Class SC Material*—Manufacturers may use their quality control systems to assure production conforms with this specification. In case of dispute regarding the quality of a delivered product, five test sheets and five adhesion specimens shall be prepared, preferably from five different packages, in accordance with the following information required by the manufacturer or purchaser.

## 12. Packaging

12.1 Material shall be protected by suitable packaging to prevent damage during shipment or storage prior to installation in the solar collector.

ance with the instructions supplied with the sealing material. If one of the five sheets or adhesion specimens does not conform, an additional five sheets or adhesion specimens may be prepared and tested. If two or more of the ten sheets or adhesion specimens do not conform, the lot may be rejected.

## 11. Marking

11.1 The following information shall be marked either on the seal, packaging, label, or tag:

11.1.1 Name, brand, or trademark of the manufacturer.

11.1.2 Type and grade,

11.1.3 Compliance with Specification D 3667, and

11.1.4 Other information required by the manufacturer or purchaser.

TABLE 2 Requirements for Class SC Material Used to Seal Flat-Plate Solar Collectors

Property	Grade			ASTM Method
	2	3	4	
Ultimate elongation, min. %	200	150	100	D 412
Resistance to heating (for 166 h at 125°C)				D 865
Hardness change, max.	10	10	10	C 661
Ultimate elongation change, max. %	30	30	30	D 412
Tensile strength change, max. %	20	20	20	D 412
Volatiles lost, max. %	1	1	1	See 10.3 <sup>a</sup>
Volatiles condensable, max. %	0.1	0.1	0.1	See 10.4 <sup>a</sup>
Resistance to ozone:				D 1149
100 mPa for 166 h at 40°C				
Resistance to low temperature:				
Type C only, max. °C	-40	-40	-40	D 2137
Adhesion loss, max. cm <sup>2</sup> <sup>a</sup>	9	9	9	C 719

<sup>a</sup> This test is not required if the design precludes condensing of the volatiles on the cover plate(s) of the solar collector.

<sup>b</sup> The combined loss in bond and cohesion areas for the three specimens tested shall not exceed 9 cm<sup>2</sup>.

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TABLE 1 Requirements for Class PS Material Used to Seal Flat-Plate Solar Collectors

Property	Grade								ASTM Method
	3	4	5	6	7	8			
Ultimate elongation, min. %	350	300	250	200	150	100			D 412
Compression set, max. %:									
after 20 h at 150°C	30	30	30	30	30	30			D 395 <sup>a</sup>
after 166 h at -10°C	60	60	60	60	60	60			D 1229 <sup>a</sup>
Resistance to heating (for 166 h at 150°C) <sup>c</sup>									D 865
Hardness change, max.	10	10	10	10	10	10			D 1415 or D 2240
Ultimate elongation change, max. %	30	30	30	30	30	30			D 412
Tensile strength change, max. %	20	20	20	20	20	20			D 412
Tensile loss, max. %	1	1	1	1	1	1			See 10.3
Volatiles lost, max. %	0.1	0.1	0.1	0.1	0.1	0.1			See 10.4
Volatiles condensable, max. %	0.1	0.1	0.1	0.1	0.1	0.1			D 1149
Resistance to ozone:									
100 mPa for 166 h at 40°C									
Resistance to low temperature:									
Type C only, max. °C	-40	-40	-40	-40	-40	-40			D 2137

<sup>a</sup> Method B.

<sup>b</sup> Set to be measured at 10 s after release. Lubricated plates or polytetrafluoroethylene film is recommended if the rubber adheres to the metal compression plates during test.

<sup>c</sup> The test temperature of 150°C is used to test seals for cover plates. A seal in contact with an absorbent plate should be tested at a standard test temperature listed in Recommended Practice D 1349 next above the maximum temperature of the absorbent plate in service (which generally occurs under stagnation conditions and maximum radiation flux) but not less than 150°C. The higher test temperatures are: 175, 200, 225, and 250.

<sup>d</sup> 100 mPa of ozone partial pressure is equivalent to 100 ppm at standard atmospheric pressure (100 kPa). See new terminology on ozone content expressions described in Method D 1149.





Table 13  
General Survey of Sealant Compounds  
and Manufacturers

Sealant	Manufacturer	Type	Form	Application	Cost/4x8 Panel Cost/Watt	Lifetime/ Weathering	Cure Time	Automation Potential
HM 1150	H.B. Fuller	Butyl- isobutylene	Slugs	Hot melt extrusion	0.24 0.000857	-	-	Excellent
HM1081A	"	Hot Melt Butyl	Rope or 55/gal drum	"	\$.19 \$.00068	Excellent	10-20 secs.	Excellent
Duribbon 72-6417	National Adhesives	Hot Melt Butyl	55/gal	Hot Melt Extrusion	.20 .00070	Excellent	60 sec.	Good
4050	"	Butyl Sealant	Tape or 55/gal drum	Pressure Flow Gun	.20 .00078	Good	Tack Free 3 hrs Cure-3 days	Poor
5354	3M	Butyl Tape	50' Roll 3/8"x1/8"	-	1.32 .00471	Excellent 20 yrs	Non-Hardening	Poor
404	3M	Synthetic elastomer	55 gal drum	Pressure flow gun	0.14 0.00050	Good	Tack free 2 hrs cure-3days	Poor
1202-T	3M	Synthetic elastomer tape/ scrim	Tape	By Hand	0.33 0.00118	Excellent	Non-hardening	Poor
XA-5367	3M	Oil Soluble elastomer (polybutene)	Ribbon	By hand	0.33 0.00118	Excellent	Non-hardening	Poor
801	3M	Polysulfide	Two Part 55/gal	Mix and pump	.69 .00246	Excellent	Tack Free 20 Hrs. cure-7 days	Poor
612	3M	Polysulfide	7 lb package	Pressure flow gun	.68 .00246	Excellent	Non-hardening putty	Poor

Table 13 (Cont. Pg. 2)  
General Survey of Sealant Compounds  
and Manufacturers

Sealant	Manufacturer	Type	Form	Application	Cost/4x8 Panel Cost/Watt	Lifetime/ Weathering	Cure Time	Automation Potential
Scotch-Seal 5200	3M	Polyurethane	55 gal drum	Pressure flow gun	0.32 0.00114	Good	Tack free- 48 hrs cure-7 days	Poor
JM 3764	3M	Hot Melt	Cartridges	Hot Melt Extrusion	.36 .00128	Poor	45 Secs.	Fair
DC732	Dow Corning	1-part Silicone moisture cure	52 gal drum	Pressure flow gun	0.26 0.00094	Excellent	24 hrs	-
DC738	"	7-part silicone non-corrosive	4 1/2 gal pail	Pressure flow gun	0.51 0.00181	Excellent	24 hrs	-
DC790	"	Silicone construction sealant	-	-	-	Excellent	24 hrs	-
DC795	"	Silicone construction sealant	-	-	-	Excellent	24 hrs	-
DC3120	"	2-part silicone hi-temp	-	-	0.90 0.00321	Excellent	24 hrs	-
Eternaflex Hypalon sealant	Gibson-Homans	Hypalon	5 gal pails	Pressure flow gun	0.066 0.000236	Good	1-2 mo. for full cure	-
Eternaflex Neoprene sealant	"	Neoprene	Cartridges	Pressure flow gun	0.31* 0.00111	Good	1 week	-

Table 13 (Cont. Pg. 3)  
General Survey of Sealant Compounds  
and Manufacturers

Sealant	Manufacturer	Type	Form	Application	Cost/4x8 Panel Cost/Watt	Lifetime/ Weathering	Cure Time	Automation Potential
Black rubber sealant	Woodhill Permatex	Neoprene	Cartridges	Pressure flow gun	0.055 0.000197	Good	2 hours	-
428	PRC	Polysulfide	Two part 55/gal	Mix and pump	.29 .00104	Excellent	16 hours	Poor
438	PRC	Polysulfide	Two part 55/gal	Mix and pump	.25 .00089	Excellent	16 hours	Poor
Macromelt 6238	Henkel	Hot Melt Polyamide Resin	25 lb.bag Pellets	Hot Melt Extrusion	.28 .00100	Poor	10 Sec.	Good
Versalon* 1140	"	Hot Melt Polyamid Resin	25 lb.bag Pellets	Hot Melt Extrusion	.34 .00121	Poor	10 Sec.	Good
Z12-069	Swift Adhesives	Hot Melt	Billets	Hot Melt Extrusion	.16 .00057	Fair	32 Sec.	Good
Z12-355	"	Hot Melt	Billets	Hot Melt Extrusion	.16 .00057	Fair	80 Sec.	Good
1200	G.E.	Silicone	5 gal pail	-	0.49 0.00175	Excellent	-	-
2400	G.E.	Silicone	5 gal pail	-	0.45 0.00161	Excellent	-	-
Silpruf	G.E.	Silicone	5 gal pail	-	0.48 0.00171	Excellent	-	-

Table 13 (Cont. Pg. 4)

General Survey of Sealant Compounds  
and Manufacturers

Sealant	Manufacturer	Type	Form	Application	Cost/4x8 Panel Cost/Watt	Lifetime/ Weathering	Cure Time	Automation Potential
RTV 103	G.E.	Silicone	5 gal pail	-	0.52 0.00186	Excellent	-	-
Dymeric	Tremco	3 part polyurethane	2 gal Container	-	0.25 0.000893	Good	-	-
THC900	"	2 part polyurethane	2 gal container	-	0.28 0.00101	Fair	-	-
Proglaze	"	Silicone	Cartridge	-	0.52 0.00185	Excellent	-	-
Butyl Sealant	"	Butyl	5 gal. drum	Pressure flow gun	0.14 0.000488	Excellent	Non-hardening	-
440 Tape	"	Butyl tape	Tape	-	0.44 0.00156	Excellent	Non-hardening	-
Mono	"	1 part Acrylic	2 gal container	Pressure flow gun	0.28 0.00102	Excellent	-	-
Acrylic Latex caulk	"	Acrylic latex	5 gal drum	Pressure flow gun	0.11 0.000377	Fair	1 hr.	-